High-speed, high-resolution imaging near surfaces

Volker Sick

The University of Michigan

QLDL

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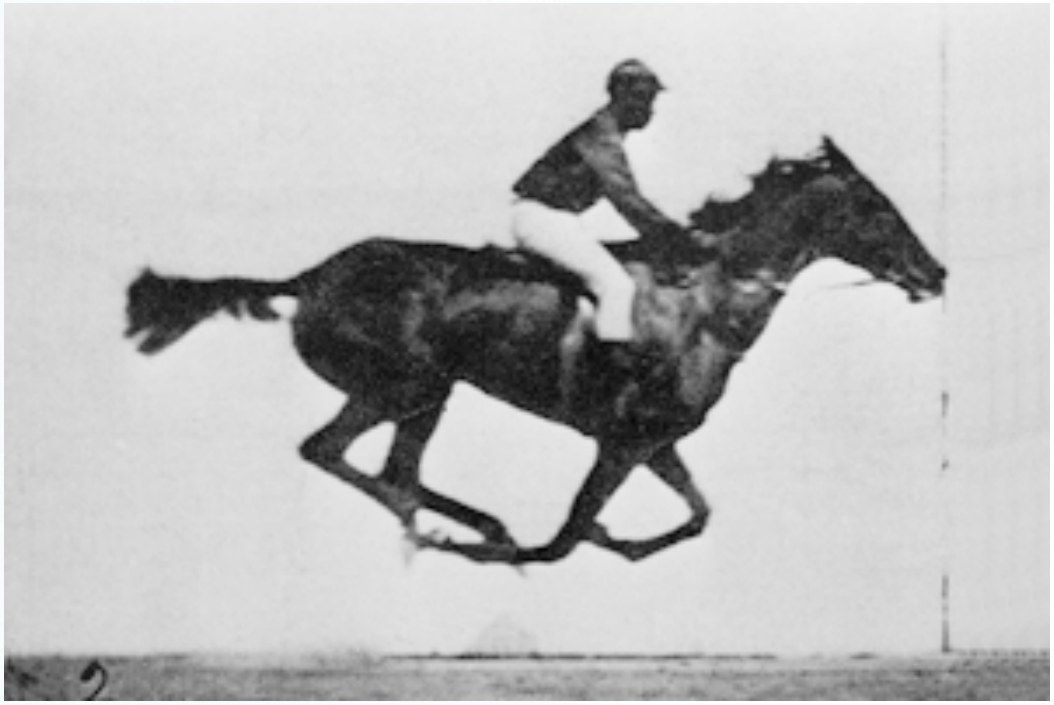

1878 Eadweard Muybridge

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Session on “Extreme Gradients”

- General challenges in imaging in the presence of extreme gradients in time and space
- Wall layers in internal combustion engines
  - Velocities
  - Temperature
- Why is this important and interesting?

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Motivation for Reciprocating IC Engine Wall Layer Measurements

- Heat Transfer
  - Borman and Nishiwaki, **1987**, Prog Energy Combust. Sci. , "Internal-Combustion Engine Heat Transfer".

    Comprehensive near-wall measurements still unavailable

  - Rakopoulos, Kosmadakis, & Pariotis, 2010, Applied Energy, "Wall Models in **RANS** calculations".
  - Piomelli & Balaras, 2002, Annul Review Fluid Mechanics, "Wall-Layer Models for **LES**"

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Sponsors

- National Science Foundation (CBET, Fluid Dynamics Division), USA
- General Motors Collaborative Research Laboratory on Engine Systems Research at the University of Michigan
- The University of Michigan, USA
- Fraunhofer USA & Fraunhofer Germany
- Center of Smart Interfaces, TU Darmstadt, Germany
- Public Authority for Applied Education and Training, Kuwait

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Credits

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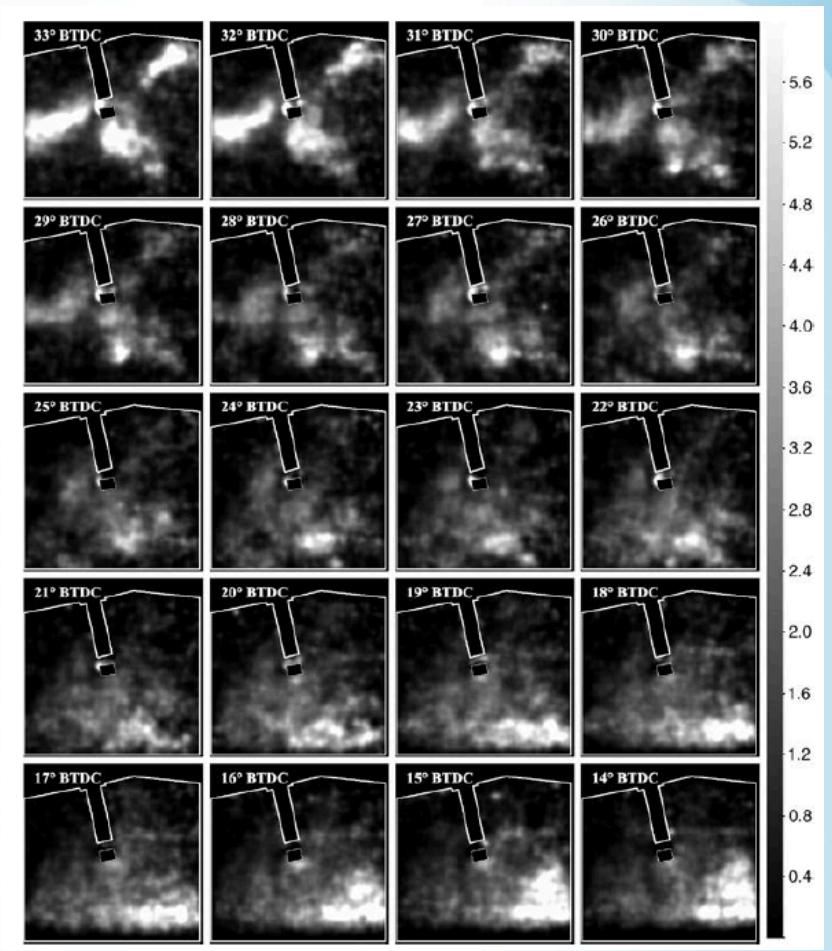
Session on “Extreme Gradients”

- Changes in observables
  - happening fast and not repeatable (μs)
    - Need movie cameras
  - over short distances (μm)
    - Need microscopes



Smith and Sick, Applied Physics B 2005

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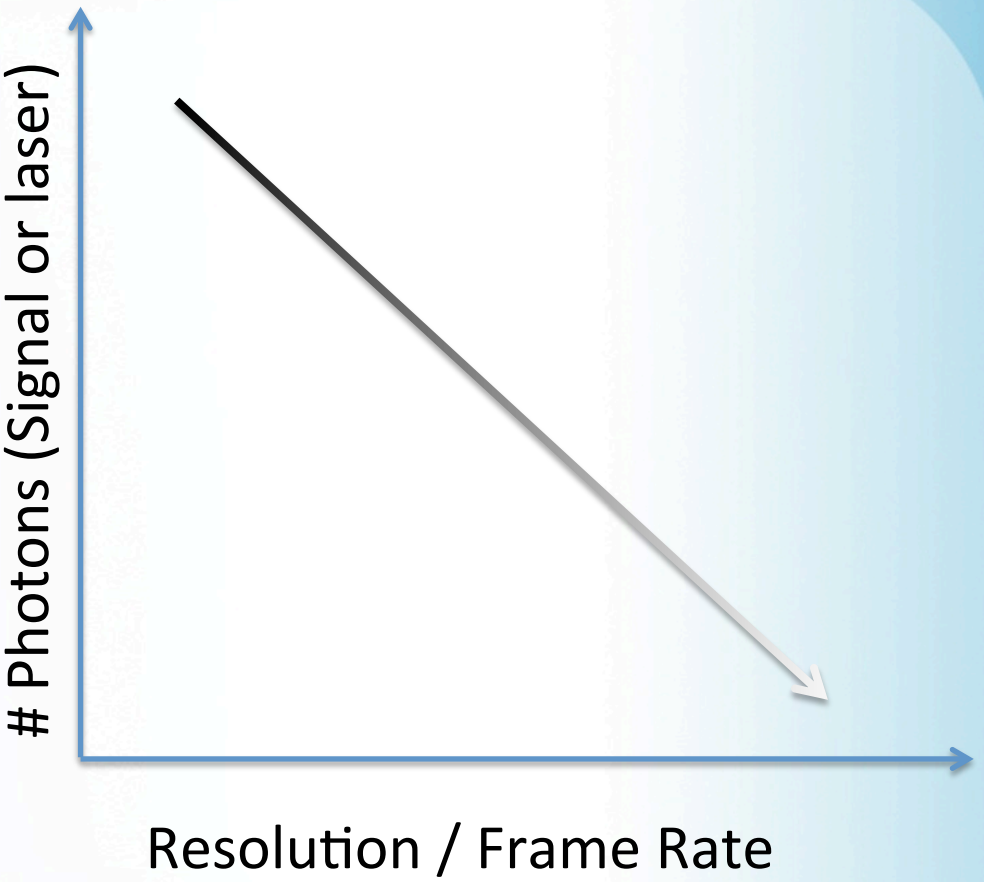
Challenges (some of more…)

- Signal strength
  - Doubling spatial resolution in LIF reduces signal by factor 8
- Laser pulse energy
  - Operating at limit of optical materials
  - Damaging surfaces
- Imaging systems
  - Camera noise
  - Intensifier issues



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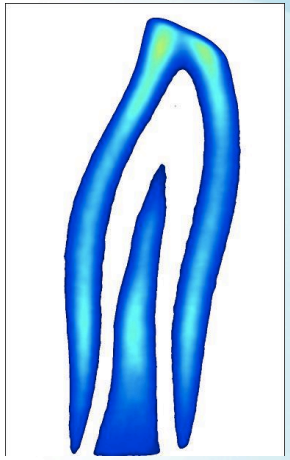
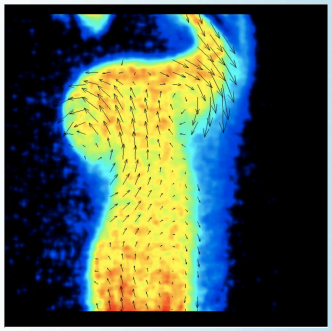
Laser induced fluorescence

- Traditional
  - 100 mJ/pulse
  - 0.5*0.2*0.2 mm measurement volume



- High-speed, high-resolution
  - 1 mJ/pulse
  - 0.1*0.02*0.02 mm measurement volume



- Signal reduction > 10^4

Particle Image Velocimetry

- 5-10 particles/interrogation window
- Increasing spatial resolution means increasing seeding density
  - From drizzle to downpour

davidkhardmanphotography.blogspot.com

http://www.telegraph.co.uk/topics/weather/8117127/Fortnight-of-rain-to-fall-in-24-hours.html

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Wall Layers in IC Engines

- Not the result of steady-mean shear
- Free stream contains large-scale structures compressed (10:1) $\rightarrow$ ΔP, ΔT, ΔL
- Wall region experiences variability of large scale/large KE structures
  - Intra cycle
  - Cycle-to-cycle
  - Flow reversal
  - Cylinder wall covered/exposed by piston.

$\rightarrow$ unsteady

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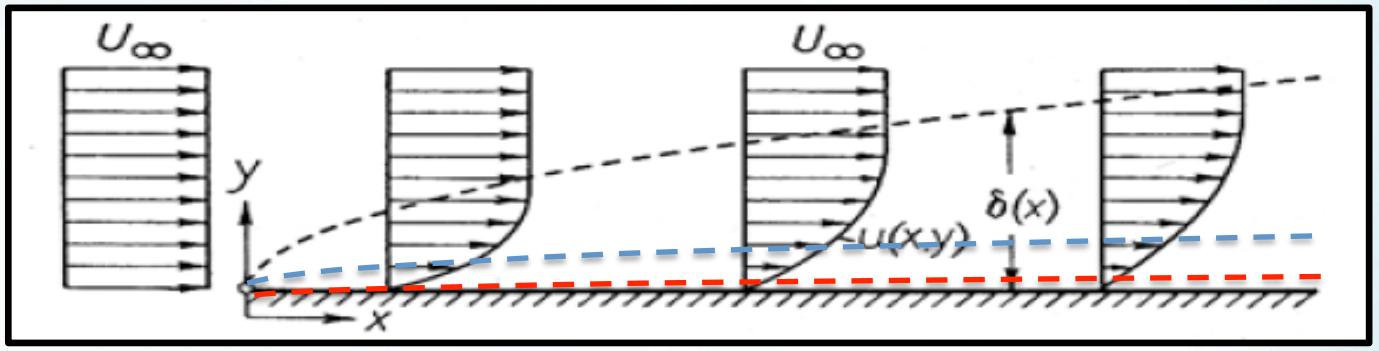
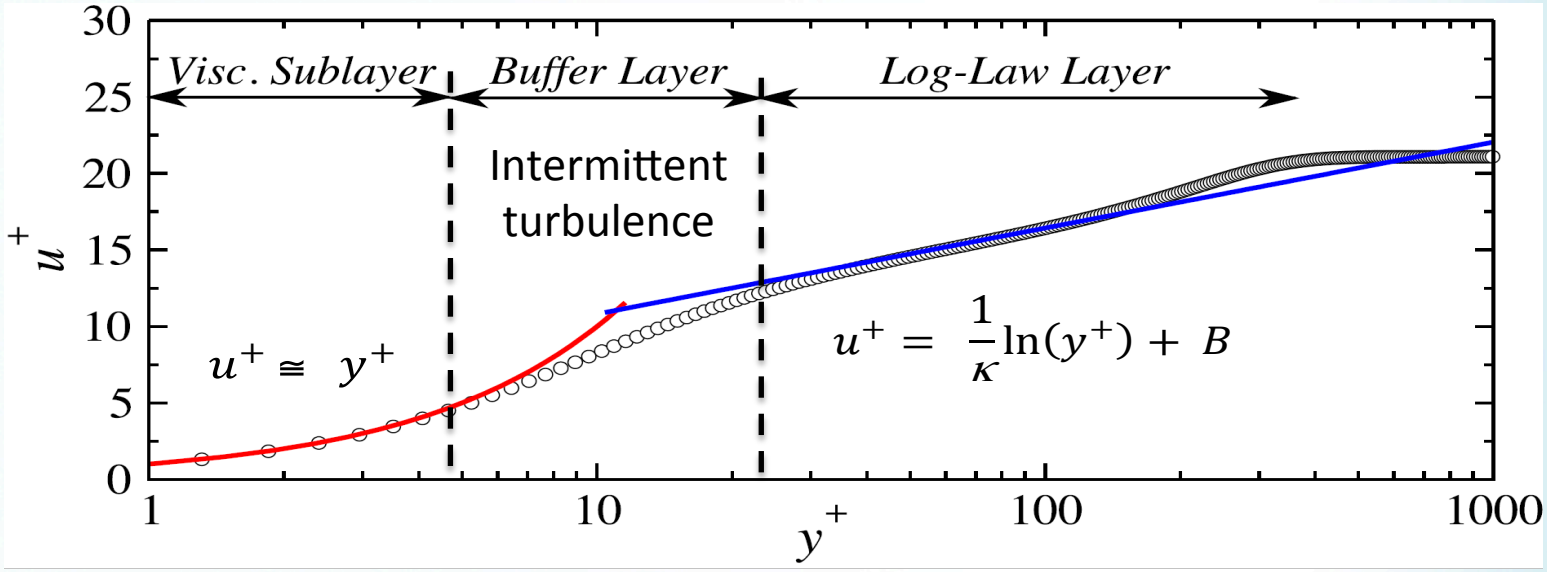
Steady flow boundary layer





Symbols correspond to direct numerical simulation results for Re = 900 (Wu & Moin, 2009).

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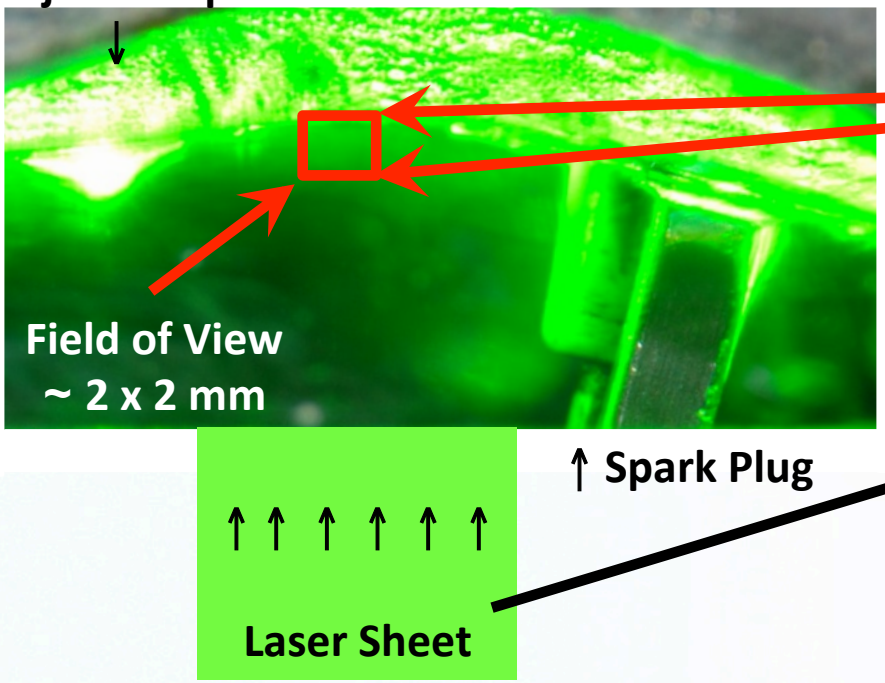
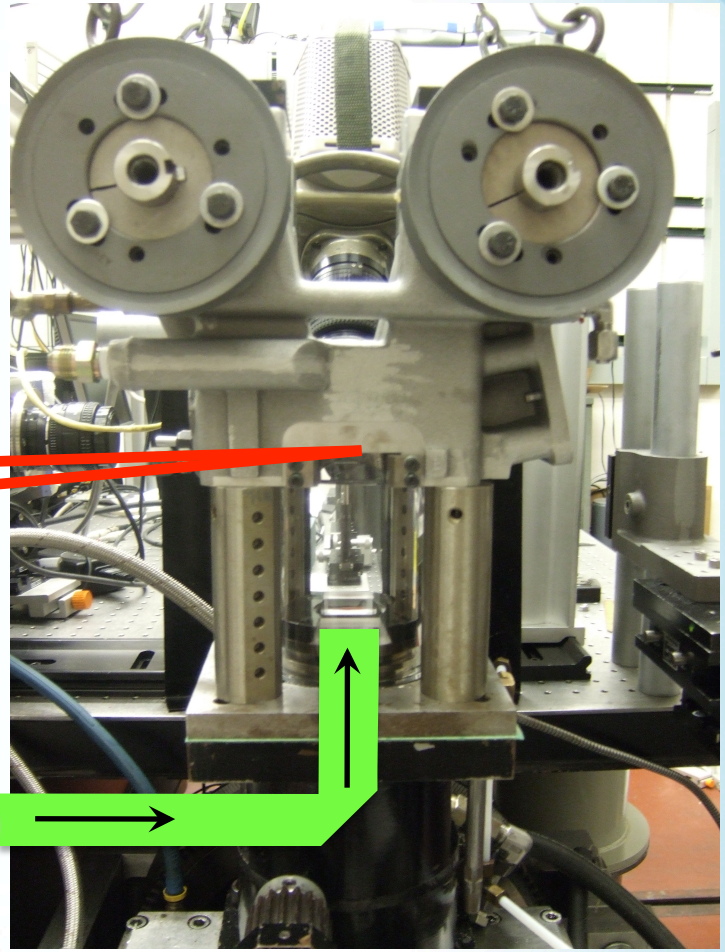
UM Stratified-Charge Spark-Ignited Direct-Injection Engine

- 4-valve pentroof combustion chamber,
- Near-central 8-hole fuel injector,
- Spray-guided spark ignition
- Motored, 800 RPM





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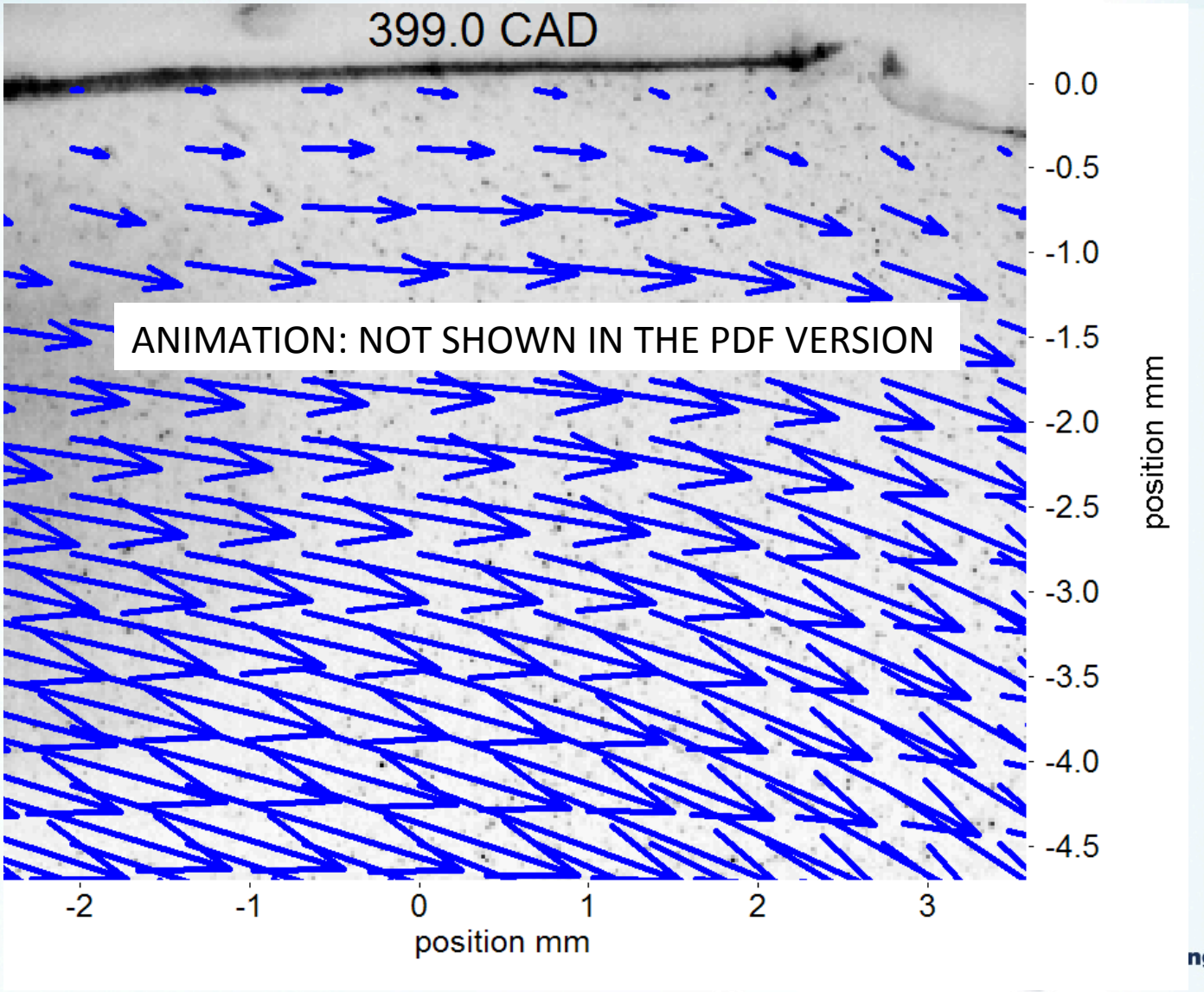
Outer flow overview, low res. PIV



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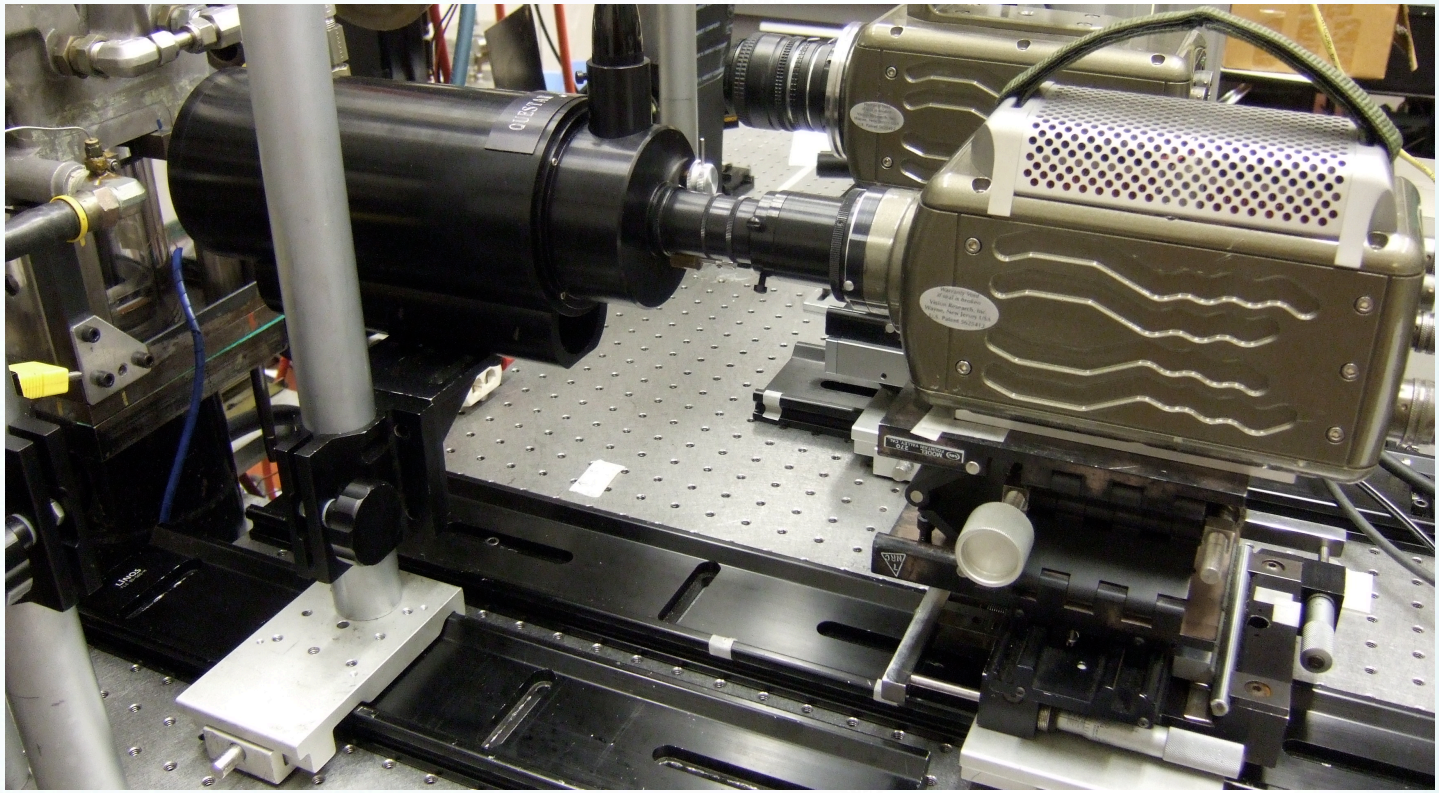
Resolving the boundary layer flow

High magnification is achieved with a long distance microscope



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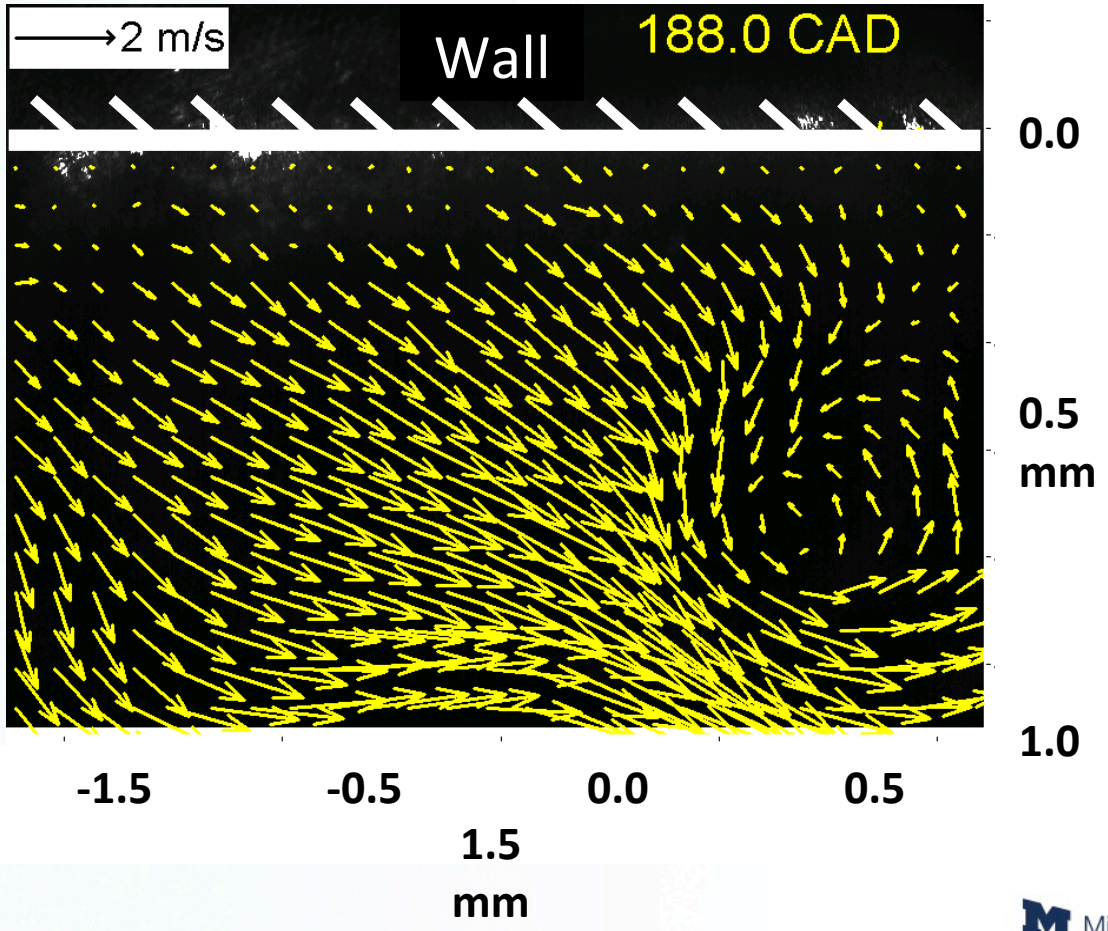
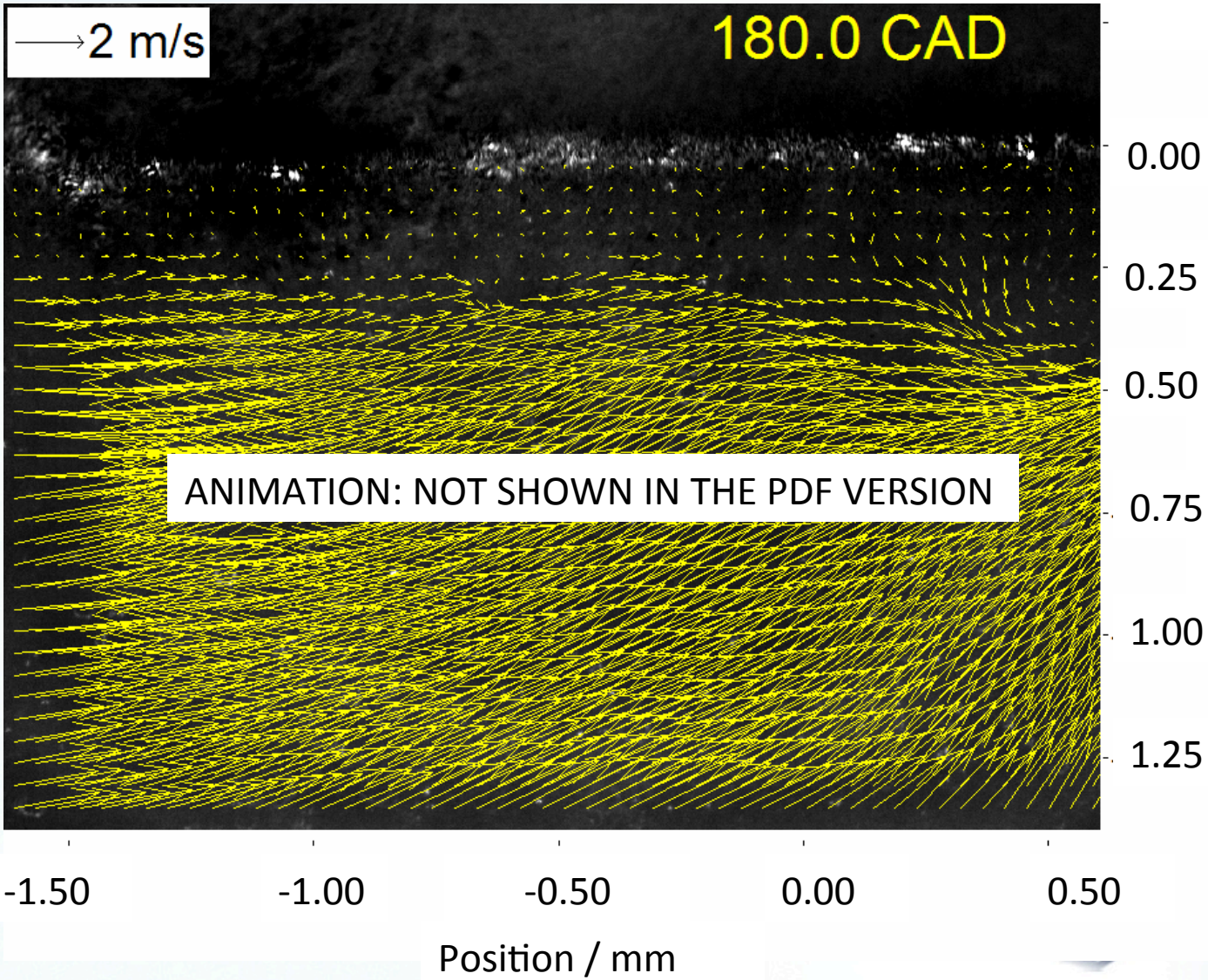
High-Speed Velocity Measurements

Movie of near wall flow during compression
every 2 degrees during one cycle

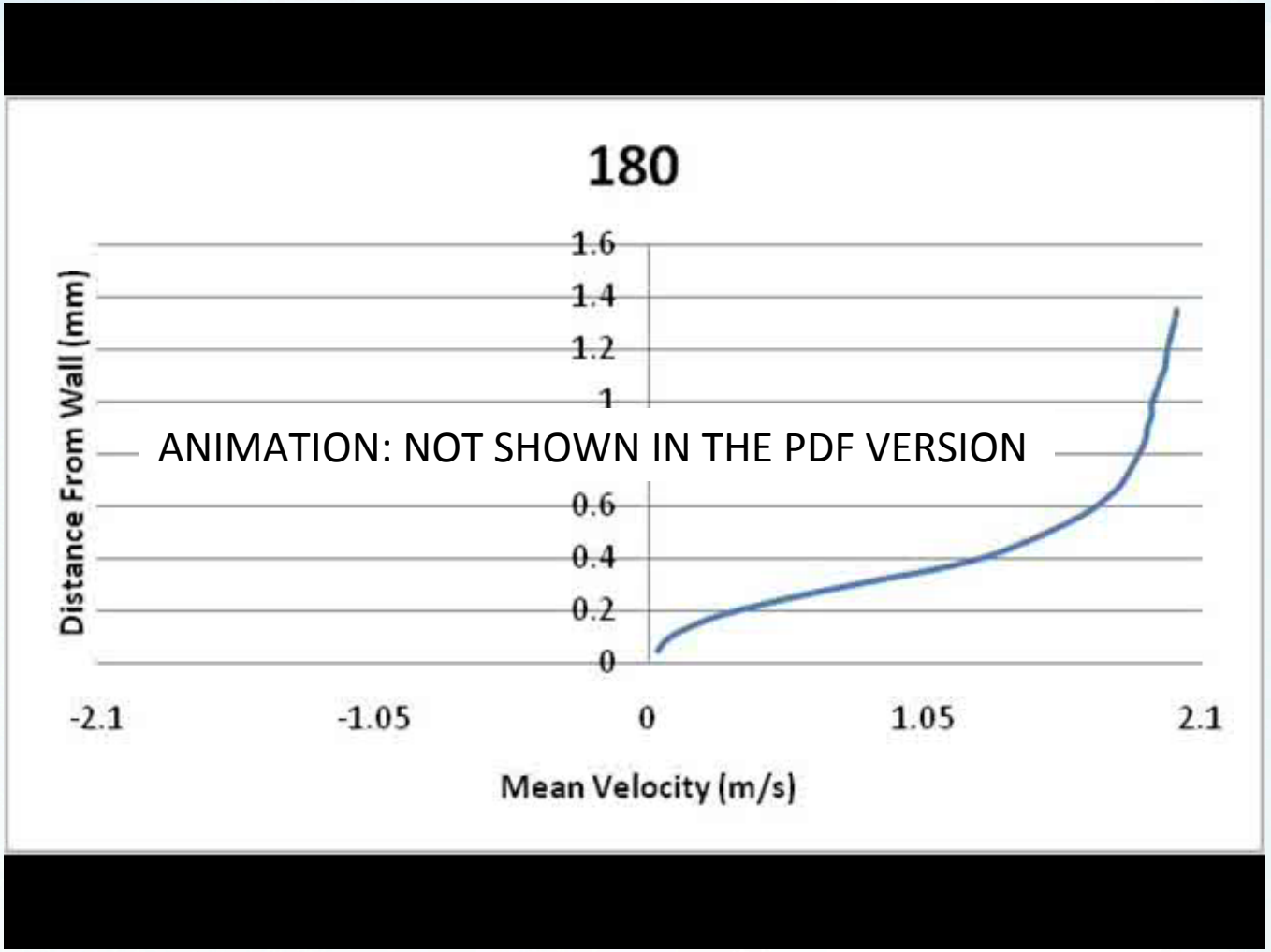


Alharbi and Sick, Experiments in Fluids 2010

High-Speed Velocity Measurements



Average velocity profile



- 180: Bottom dead center
- 360: Top dead center compression

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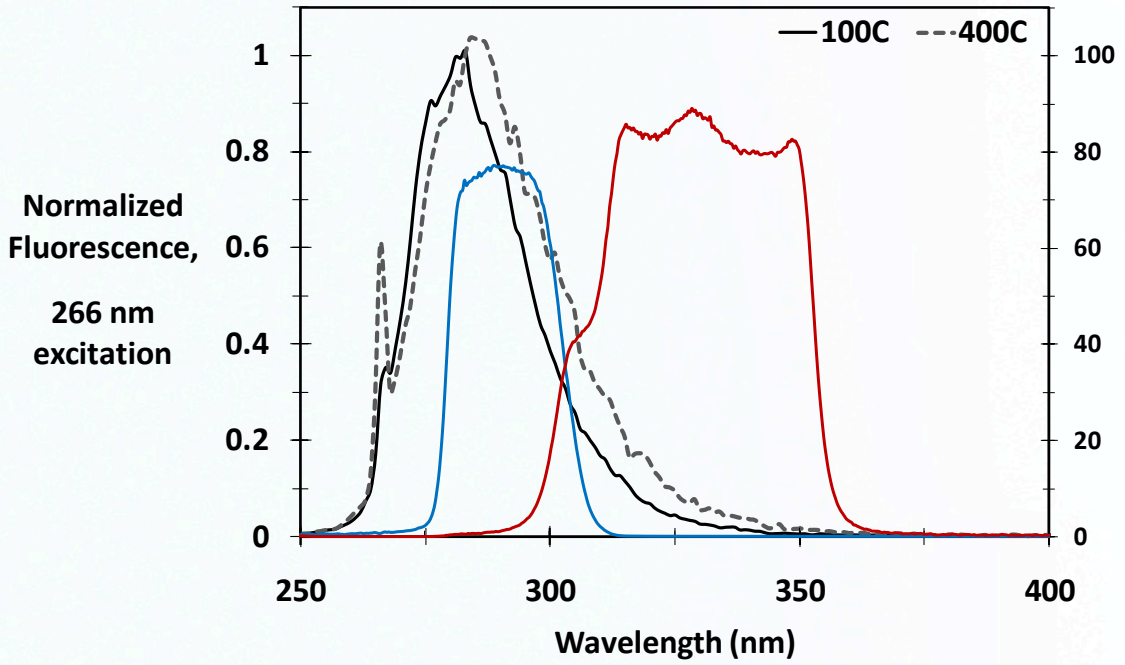
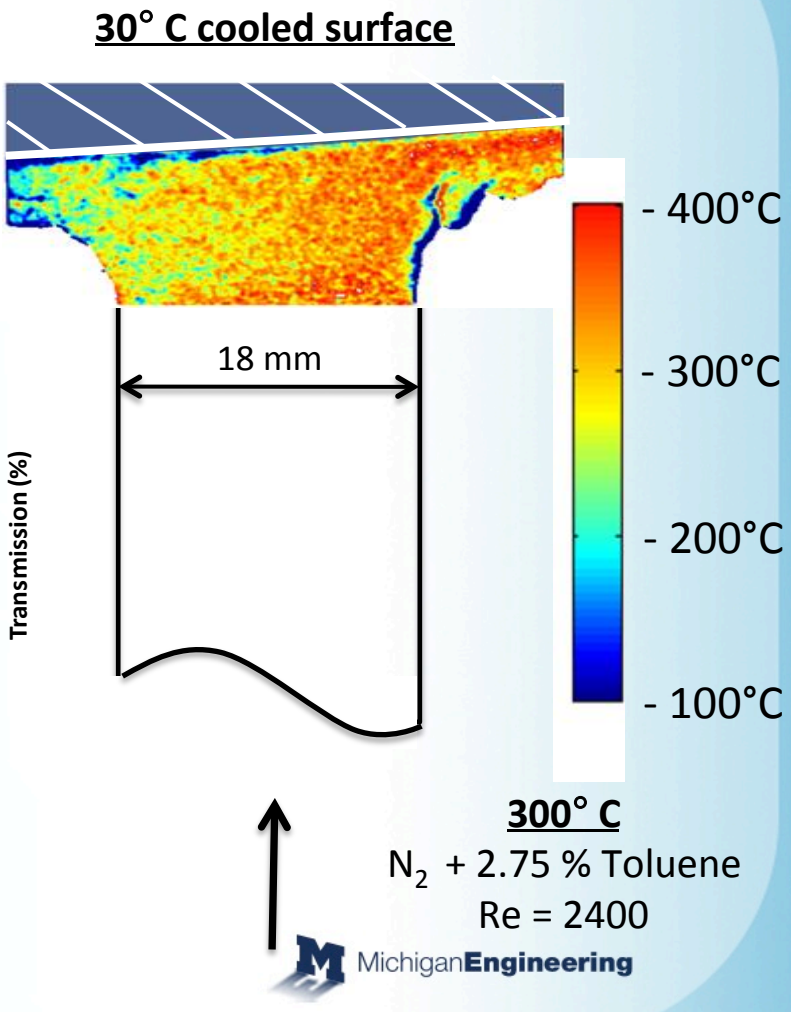
Temperature imaging in Boundary Layers

Worked done jointly with P. Trunk and A. Dreizler at TU Darmstadt

Single-excitation toluene LIF





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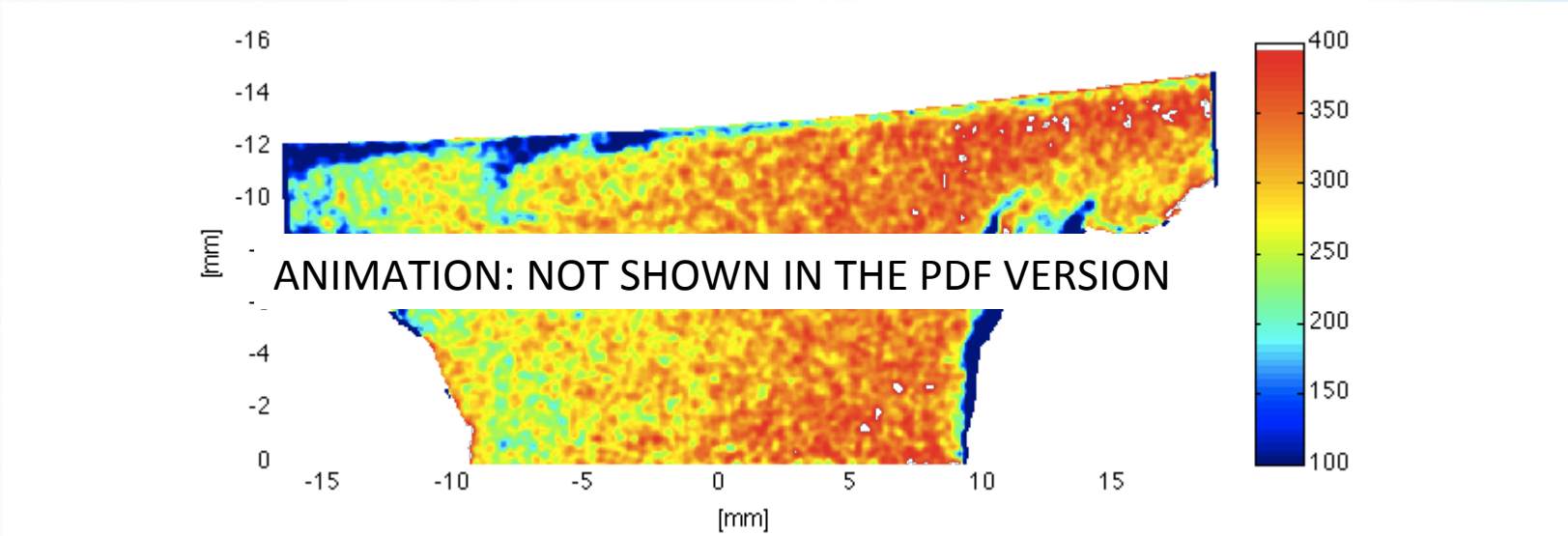
Temperature in a Boundary Layer



- Suppression of scattered laser light is adequate to obtain temperature data within the boundary layer
- Cold, detaching flares observed in boundary layer

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Cundy, Trunk, Dreizler, and Sick, Experiments in Fluids 2011

Thermal Boundary Layer in the UM Engine

One lens/camera/intensifier images both channels

- Eliminates problems with highspeed intensifier depletion
- Enables better access for additional diagnostics to the engine

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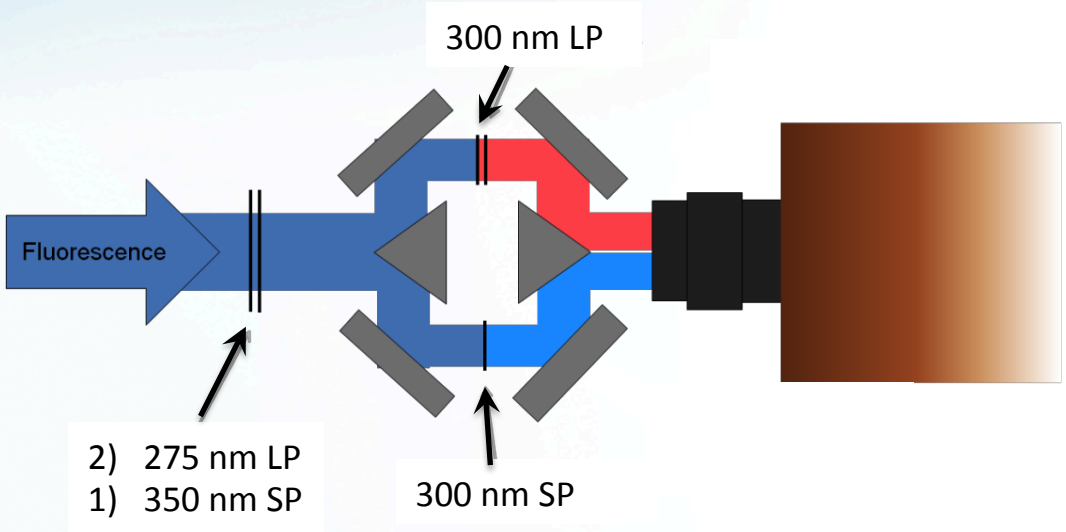
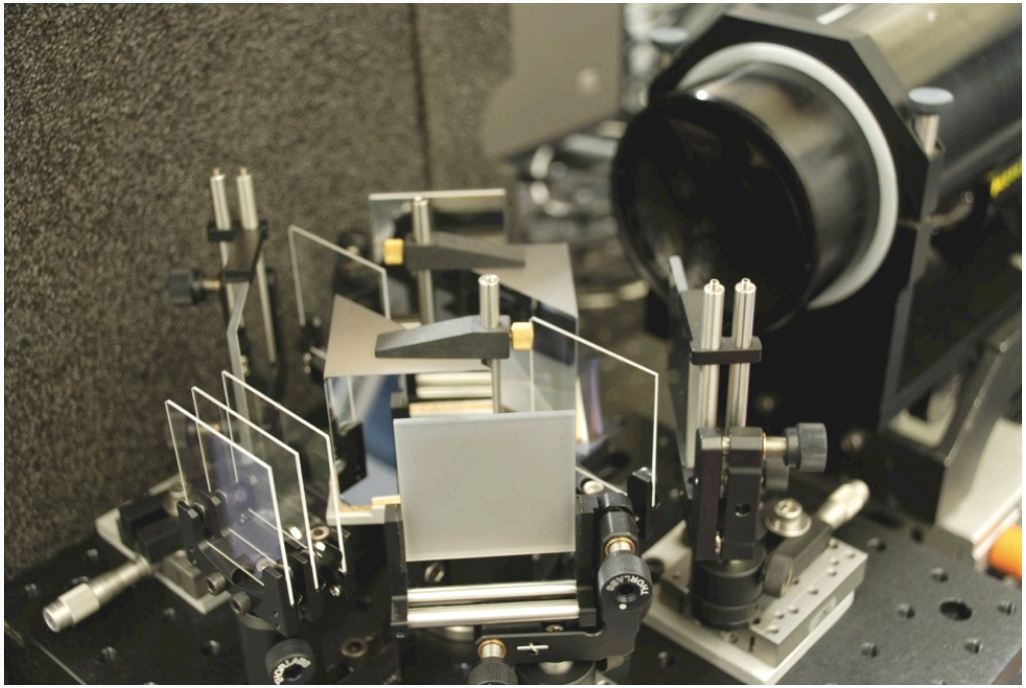
Split-Image Optics





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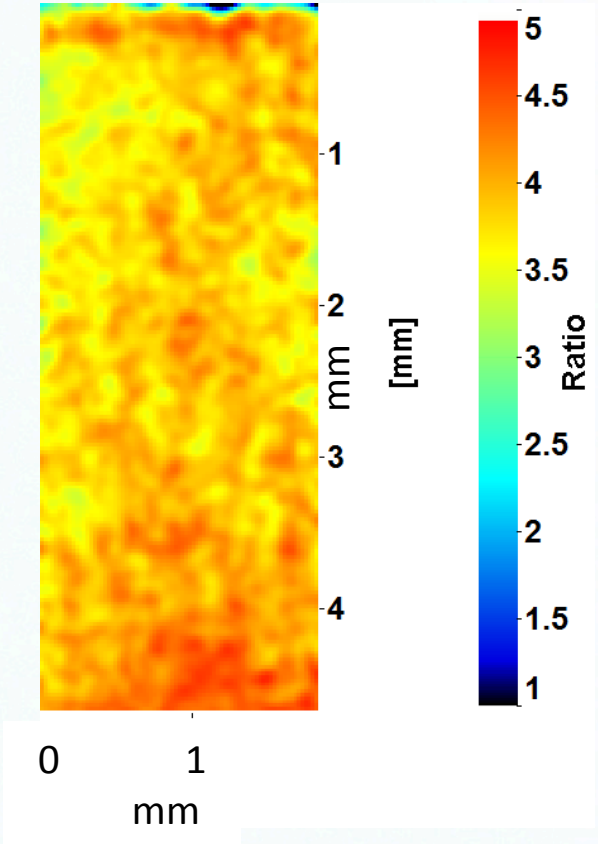
First Results



Single shot

600 rpm, motored, N_2 & Air, TDC,
20 Hz Nd:YAG, 1 image/cycle, 2 mJ/pulse

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Conclusions

- High frame rate measurements (few kHz) at micron resolution near surfaces
  - Velocity data currently put in context with existing wall models
  - Temperature imaging, feasibility shown; laser needed for high-speed imaging
  - First steps taken, but
    - Need higher frame rates, larger format cameras, and more (UV) pulse energy

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